# A Migratory Life-Cycle Release-Recapture Model for Salmonid PIT-Tag Investigations

Rebecca A. BUCHANAN and John R. SKALSKI

Since 1987, millions of juvenile salmonids (smolts; *Oncorhynchus* species) in the Snake and upper Columbia rivers have been tagged with Passive Integrated Transponder (PIT) tags, and detected at hydroelectric projects as they migrate downriver to the Pacific Ocean. Since the late 1990s, detection of PIT-tagged adults has been possible at some dams. Existing release-recapture models are designed for either juvenile data or adult data, but not both. We present a migratory life-cycle release-recapture model that follows tagged individuals from their release as juveniles through their return migration as adults, accounting for downstream barge transportation of juveniles, right-censoring due to known removals at dams, and adult age at maturity. This branching model estimates river survival, age-specific probabilities of adult return, and relative effects of smolt transportation on survival. Performance measures are defined using model parameters. We analyze a dataset of 58,447 PIT-tagged summer Chinook salmon released in 2000 in the Snake River. For nontransported fish, juvenile survival from passage at Lower Granite Dam to Bonneville Dam was estimated at 60.3% ($\widehat{\text{SE}} = 8.1\%$), and the ocean return probability to Bonneville was estimated at 4.5% ($\widehat{\text{SE}} = 0.7\%$). The smolt-to-adult ratio (SAR) for the entire release group was estimated at 2.0% ($\widehat{\text{SE}} = 0.09\%$), and perceived inriver adult survival was estimated at 87.1% ($\widehat{\text{SE}} = 1.7\%$).

**Key Words:** Age-class model; Chinook salmon; Columbia River; Mark-recapture; Smolt-to-adult ratio; Smolt transportation.

## 1. INTRODUCTION

Pacific salmonids (*Oncorhynchus* spp.) make two migrations in their life cycle. The juvenile (smolt) outmigration is from freshwater rearing grounds to the Pacific Ocean; the adult upriver migration is from the Pacific Ocean back to the spawning grounds. Salmonids from the lower Snake River Basin pass eight large hydroelectric dams on the Snake and Columbia Rivers during both their migrations (Figure 1); upper Columbia River salmonids pass up to nine dams on their migrations. At three Snake River dams and one Columbia River dam, smolts are collected for transportation downriver by barge or truck, and returned to the river downstream of Bonneville Dam (river kilometer [RKM] 234), the dam closest to

Rebecca A. Buchanan is Research Scientist, School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA (E-mail: *rabuchan@u.washington.edu*). John R. Skalski is Professor, School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA (E-mail: *jrs@cbr.washington.edu*).


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Table 6. Modified $m$-array (LGR-transport group) for hatchery summer Chinook salmon released in the Snake River above LGR in 2000. Adult age classes are: 1 = 2001 adults (jacks); 2 = 2002 adults; 3 = 2003 adults. The first column identifies the release site for the row.

| Site | | Adult Detection Sites | | | | | | Number |
|---|---|---|---|---|---|---|---|---|
| | | BON | | | LGR | | | |
| (Age Class) | Release | (1 | 2 | 3) | (1 | 2 | 3) | recaptured |
| LGR | 8,557 | 44 | 327 | 123 | 22 | 8 | 2 | 526 |
| BON (1) | 41 | | | | 36 | | | 36 |
| BON (2) | 327 | | | | | 283 | | 283 |
| BON (3) | 123 | | | | | | 92 | 92 |
| Number detected | | 44 | 327 | 123 | 58 | 291 | 94 | |
| Number censored | | 3 | 0 | 0 | | | | |

Goodness-of-fit was assessed with tests based on Test 2 and Test 3 of Burnham et al. (1987), and standard errors were expanded to account for overdispersion using a resultant inflation factor of 1.677 (Lebreton et al. 1992). Survival of nontransported juveniles from LGR to BON was estimated at 0.6028 ($\widehat{SE} = 0.0813$). In general, standard errors on survival estimates increased going downriver, because of effectively smaller sample sizes as fish were lost due to mortality or removal: $\widehat{\mathrm{SE}}(\hat{S}_1) = 0.0114$, $\widehat{\mathrm{SE}}(\hat{S}_3) = 0.0479$, and $\widehat{\mathrm{SE}}(\hat{S}_6) = 0.1045$. Although adult detections allow for estimation of smolt survival in the lowest reach (ending at BON), they provide little information on inriver survival of smolts in the upper reaches because so few smolts return as adults. Thus, improved adult detection cannot replace downriver juvenile detection requirements.

The estimated ocean return probability (i.e., BON to BON) for nontransported fish was $\hat{O}_{\mathrm{NT}} = 0.0445$ ($\widehat{\mathrm{SE}} = 0.0067$), meaning that approximately 4.5% of the nontransported fish who survived to BON returned to BON as adults. Because $O_{\mathrm{NT}}$ includes survival of juveniles from BON to the ocean (234 km) and survival of adults from the ocean back to BON, actual ocean survival is higher than the 4.5% estimated.

Table 7. Modified $m$-array (LGO-transport group) for hatchery summer Chinook salmon released in the Snake River above LGR in 2000. Adult age classes are: 1 = 2001 adults (jacks); 2 = 2002 adults; 3 = 2003 adults. The first column identifies the release site for the row.

| Site | | Adult Detection Sites | | | | | | Number |
|---|---|---|---|---|---|---|---|---|
| | | BON | | | LGR | | | |
| (Age Class) | Release | (1 | 2 | 3) | (1 | 2 | 3) | recaptured |
| LGO | 3,166 | 10 | 87 | 28 | 9 | 2 | 1 | 137 |
| BON (1) | 9 | | | | 8 | | | 8 |
| BON (2) | 87 | | | | | 76 | | 76 |
| BON (3) | 28 | | | | | | 22 | 22 |
| Number detected | | 10 | 87 | 28 | 17 | 78 | 23 | |
| Number censored | | 1 | 0 | 0 | | | | |